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(54) Title: BIFURCATED SHUNT DRUG DELIVERY SYSTEM AND METHODS OF USE

(57) Abstract: Bifurcated intraluminal shunt devices and methods of their use for delivering a drug or other fluid to a target vessel of a patient while maintaining perfusion of blood through the vessel to reduce ischemia downstream of the vessel are disclosed.

BIFURCATED SHUNT DRUG DELIVERY SYSTEM AND METHODS OF USE

TECHNICAL FIELD

The present invention relates generally to drug or fluid delivery devices and methods. More particularly, the present invention relates to bifurcated intraluminal shunt devices for delivering a drug or fluid to the vessel of the patient, while maintaining blood perfusion through the vessel, and which may be used, for example, in coronary artery bypass graft procedures.

BACKGROUND OF THE INVENTION

Minimally invasive surgical techniques (*e.g.*, avoidance of cardiopulmonary bypass support and avoidance of use of a sternonomy incision) have revolutionized cardiac surgery. Minimally invasive cardiac surgery enjoys the advantages of reduced morbidity, quicker recovery times, and improved cosmesis over conventional cardiac surgery procedures.

One approach to minimally invasive cardiac surgery is coronary artery bypass grafting ("CABG") on a beating heart. Anastomosis between a stenotic coronary artery and a bypass graft vessel may present obstacles including myocardial ischemia (or arrhythmia induced by the transient period of coronary artery occlusion necessary for coronary arrest), significant bleeding into the operative field from septal bleeders despite adequate epicardial coronary artery occlusion, inability to graft the left circumflex system due to hemodynamic sequelae induced by lifting the heart, and continuous cardiac translational motion which may impair meticulous microsurgical placement of graft sutures.

For CABG on a beating heart to be universally accepted, the superior patency rates of traditional "on pump" graft procedures, such as grafting the internal thoracic artery to the left anterior descending artery (LAD), can not be compromised. A major obstacle to safe and precise coronary anastomosis is the constant motion of the beating heart. Surgical approaches have been developed to stabilize the heart and facilitate anastomosis. Most new approaches employ some form of mechanical stabilization to stabilize the beating heart, such as the "fork-shaped" coronary artery stabilizer manufactured by CardioThoracic Systems, Inc. and described in Boonstra, P.W., Grandjean J.G., Mariani, M.A., Improved

Method for Direct Coronary Grafting Without CPB Via Anterolateral Small Thoracotomy, Ann. Thorac. Surg. 1997;63:567-9. The coronary artery stabilizer in combination with an access platform in which it sits helps stabilize the left anterior descending artery on the beating heart and permits an arteriotomy with a conventional scalpel and scissors. In addition, many other different technologies that allow local coronary wall immobilization have been developed, including various platform devices and the Utrecht "Octopus" device in which suction pods are placed adjacent the coronary artery. The suction immobilization simulates the arrested condition locally (see, *e.g.*, Borst C., Jansen E.W.L., Tulleken C.A.F., et al., Coronary Artery Bypass Grafting Without Cardiopulmonary Bypass and Without Interruption of Native Coronary Flow Using a Novel Anastomosis Site Restraining Device ("Octopus"), J. Am. Coll. Cardiol. 1996;27:1356-64).

However, precise vascular anastomosis using mechanical stabilization techniques may be elusive due in large part to the inherent difficulties in maintaining uniform and steady pressure on opposite sides of the target diseased vessel, such as the LAD. Moreover, the constant translational motion of the heart and bleeding from the opening in the coronary artery can hinder precise suture placement in the often tiny coronary vessel. Although bleeding can be reduced by using proximal and distal coronary occluders, by excluding diagonal and septal branches near the arterial opening when possible, and by continuous saline irrigation or humidified carbon dioxide insufflation, the incessant motion of the beating heart may be the Achilles' heel of minimally invasive coronary artery bypass surgery.

In response to problems associated with mechanical stabilization techniques, a new technique has been developed to minimize the cardiac motion which employs a novel pharmaceutical approach to stabilizing the heart. This revolutionary pharmaceutical approach to cardiac stabilization is described in patent application PCT/US98/16469, publication number WO 99/07354, entitled Compositions, Apparatus and Methods For Facilitating Surgical Procedures, and having Francis G. Duhaylongsod as the named inventor and an international filing date of August 7, 1998. WO 99/07354 is hereby expressly incorporated by reference herein in its entirety. As described therein, pharmaceutical compositions and methods are provided which are useful for medical and surgical procedures which may benefit from precise control of cardiac contraction, such as coronary artery bypass procedures. In one embodiment of that invention, a pharmaceutical

composition is provided that is capable of inducing reversible ventricular asystole in a patient, while maintaining the ability of the heart to be electrically paced. "Reversible ventricular asystole" refers to a state wherein autonomous electrical conduction and escape rhythms in the ventricle are suppressed. A state of the heart may be induced wherein the heart is temporarily slowed to at least about 25 beats per minute or less, and often about 12 beats per minute or less. The induced ventricular asystole is reversible and after reversal, the heart functions are restored, and the heart is capable of continuing autonomous function. Various drug delivery methods are disclosed to facilitate drug delivery to coronary vessels.

United States Patent No. 5,695,504 to Gifford et al. discloses a catheter device for isolating a section of a coronary artery while performing a distal anastomosis. The catheter device includes a T-shaped distal portion which includes a single dedicated blood and/or fluid delivery lumen which allows blood to flow through the device downstream from the anastomosis site. A single side perfusion limb is provided which is in fluid communication with the main perfusion lumen for infusing blood and/or cardioplegia solution into the catheter if the passive blood flow through the main perfusion lumen is insufficient because of a severe stenosis or total occlusion upstream of the anastomosis site.

Bifurcated shunts have been used by surgeons to reduce intraoperative ischemia during aortic aneurysm repair procedures, as disclosed in United States Patent No. 3,435,824 to Gamponia and United States Patent No. 5,453,084 to Moses, as well as in other procedures such as liver transplantation, as disclosed in United States Patent No. 5,879,321 to Hill, endarterectomy procedures, as disclosed in United States Patent No. 5,876,367 to Kaganov *et al.*, arterial repair procedures such as carotid artery repair procedures, as disclosed in United States Patent No. 5,374,239 to Mischenko, and aortic bypass operations, as disclosed in United States Patent No. 4,712,551 to Rayhanabad.

Intraluminal shunts are employed by surgeons to reduce intraoperative ischemia and facilitate the construction of coronary artery bypass grafts. For example, the Rivetti-Levinson™ intraluminal shunt (from Heyer-Schulte NeuroCare Group) (patent pending) employs a standard T or L-shaped intraluminal shunt having a main shunt body which is configured to be inserted into a coronary artery vessel and which provides direct or passive perfusion of the distal coronary arterial lumen during construction of coronary bypass grafts in the non-arrested heart. A side port is provided to actively perfuse the coronary

artery from a secondary source using a standard luer connection. However, this device is specifically not designed nor intended for drug administration into the coronary artery vessel or other vessels supplying the AV node.

It remains desirable to provide new intraluminal shunt devices for delivery of drugs or other fluids directly into the lumen of a vessel.

SUMMARY OF THE INVENTION

The present invention involves bifurcated intraluminal shunt apparatus which can be used to deliver a drug and/or other fluid to a vessel of a patient undergoing a surgical procedure, such as a CABG procedure, while maintaining either passive or active blood perfusion through the vessel.

According to one aspect of the invention, a bifurcated intraluminal shunt is provided with a bifurcated perfusion lumen and an independent fluid (e.g., drug) delivery lumen. With this construction, one may administer a drug or fluid into a second vessel, which branches from a first vessel, while maintaining blood perfusion through both the first and second vessels. This construction also facilitates precisely delivering a fluid, such as a drug, where it may be most effective independent of local fluid flow patterns in the patient. This may reduce the amount of drug required to be delivered to the patient to effect the desired result. For example, the shunt, which may be described as having first, second and third legs can facilitate drug delivery to a single downstream vascular branch when two legs are positioned in a vessel location downstream from the other leg. Since drug may be prevented from being delivered to the second downstream leg where drug delivery may be undesirable, less drug need be administered.

According to another aspect of the invention, the bifurcated shunt apparatus includes three legs adapted to be inserted into branched vessels of a human patient, such as the right coronary artery, the posterior descending artery, and the interventricular branch artery.

In a further embodiment, a kit for conducting a surgical procedure is provided comprising: a pharmaceutical composition capable of inducing reversible ventricular asystole in the heart of a patient while maintaining the ability of the heart to be electrically

paced; and a bifurcated intraluminal shunt having a bifurcated perfusion lumen and an independent fluid (e.g., drug) delivery lumen.

According to one method of the present invention, a bifurcated intraluminal shunt having first, second and third legs is placed in a human patient with one leg extending into the interventricular branch and delivering through the leg extending into the interventricular branch a pharmaceutical composition capable of inducing reversible ventricular asystole in the heart of the patient while maintaining the ability of the heart to be electrically paced. The method may include forming an opening in a coronary vessel and delivering the shunt through the opening such that the drug delivery leg extends into the interventricular branch. The bifurcated intraluminal shunt apparatus also may be placed at the site of an anastomosis in accordance with the present invention.

The above is a brief description of some deficiencies in the prior art and advantages of the present invention. Other features, advantages, and embodiments of the invention will be apparent to those skilled in the art from the following description, accompanying drawings and/or claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view of one embodiment of a bifurcated intraluminal shunt apparatus according to the present invention.

Fig. 2A is a sectional view of another embodiment of a bifurcated intraluminal shunt apparatus according to the present invention.

Fig. 2B is a sectional view of the bifurcated intraluminal shunt apparatus of FIG. 2A taken along line 2B-2B.

Fig. 2C is a sectional view of the bifurcated intraluminal shunt apparatus of FIG. 2A taken along line 2C-2C.

Fig. 2D is a sectional view of the bifurcated intraluminal shunt apparatus of FIG. 2A taken along line 2D-2D.

Fig. 3 is a sectional view of the bifurcated intraluminal shunt apparatus of FIG. 2A shown inserted into the right coronary artery, posterior descending artery and interventricular branch artery of a patient.

Fig. 4 is a sectional view of an alternative construction of the bifurcated intraluminal shunt apparatus of FIG. 2A.

Fig. 5 is a sectional view of another embodiment of the bifurcated intraluminal shunt apparatus according to the present invention.

Fig. 6 is a sectional view of another embodiment of the bifurcated intraluminal shunt apparatus according to the present invention.

Fig. 7A is a sectional view of another construction of the bifurcated intraluminal shunt apparatus according to the principles of the invention in an unassembled state.

Fig. 7B is a sectional view of the shunt of Fig. 7A in an assembled state.

DETAILED DESCRIPTION OF THE INVENTION

Bifucated shunt apparatus constructed according to the principles of the present intention will now be described in detail with reference to the accompanying drawings wherein like numerals indicate like elements. The shunt generally comprises bifurcated tubing adapted for placement within the vasculature of the body of a patient, which can deliver fluids to a desired vessel while maintaining blood flow through the vessel.

Referring to Fig. 1, a first embodiment of a bifurcated intraluminal shunt apparatus constructed in accordance with the present invention is shown and is generally designated with reference numeral 10. Bifurcated intraluminal shunt 10 can be constructed of any suitable biocompatible material(s) which provides sufficient flexibility to facilitate insertion of the apparatus into the target vessels. Moreover, the material may be sufficiently rigid to maintain its shape within the target vessels to allow for safe and efficient blood flow through the apparatus 10. Suitable materials include polyethylene, polyurethane, nylon, or silicone, preferably silicone. The bifurcated intraluminal shunt apparatus may also be made of composite or reinforced materials.

The bifurcated intraluminal shunt apparatus 10 generally comprises three legs which form branched tubing. Two legs may be formed by a primary tubular portion 20 which has a proximal end 26 and a distal end 27. The third leg may be formed by a secondary tubular portion 70 which has a distal end 75 spaced from the primary tubular portion 20. The primary and secondary portions may be integrally formed as a single extrusion. Alternatively, these portions may be formed and joined to construct the bifurcated tubing shown in the drawings. For consistency and convenience, throughout the description the two ends of the primary tubular portion of the bifurcated intraluminal shunt apparatus are referred to as the proximal and distal ends respectively, the distal end of the

primary tubular portion is the end which is to be inserted into the downstream side of the blood vessel and the proximal end being the end which is inserted into the upstream side of the blood vessel, and the distal end of the secondary tubular portion is referred to as the bifurcation end. The primary tubular portion 20 may be linear, bent, or curved. The primary tubular portion 20 may be coupled to the secondary tubular portion 70 in a variety of ways, such as, for example, a side cut 22 to be mated with the secondary tubular portion 70 by RTV or similar adhesive. Referring to Fig. 2A, another embodiment of the invention is shown and generally designated with reference numeral 10'. As shown, the proximal, distal, and bifurcation ends 26, 27, and 75 may have a beveled configuration to facilitate insertion of the primary and secondary tubular portions 20 and 70 into the target vessels. Preferably, the proximal, distal, and bifurcation ends 26, 27, and 75 are beveled at an angle of about 30 to about 60 degrees relative to the longitudinal axis of the primary and secondary tubular portions 20 and 70, respectively, and most preferably are beveled at an angle of about 45 degrees.

The primary and secondary tubular portions 20 and 70 include a bifurcated inner blood perfusion lumen 21 which extends longitudinally between a proximal blood perfusion port 28 and a distal blood perfusion port 23 and a bifurcation blood perfusion port 76 (see Fig. 2A). Blood perfusion lumen 21 allows the flow of blood through the primary and secondary tubular portions to thereby minimize or eliminate the risk of intra-operative ischemia downstream of the vessels during use of the device.

The intraluminal shunt apparatus 10' includes a tertiary tubular portion 30 (or leg) which is coupled to secondary tubular portion 70. The tertiary tubular portion 30 may be affixed by RTV or similar adhesive to primary tubular portion 20 at a variety of angles, depending on the intended target vessels.

The secondary and tertiary tubular portions 70 and 30 generally form an inner fluid delivery lumen 77 which extends longitudinally from a drug delivery port 72 at the distal end of the tertiary tubular portion 30 to a drug discharge port 79 at the end of secondary tubular portion 70. Preferably, inner fluid delivery lumen 77 is separate and independent from inner perfusion lumen 21. Although lumen 77 is shown extending to the end of portion 70, it should be understood that fluid delivery lumen 77 need not extend the entire axial length of the secondary tubular portion as shown. For example, the fluid delivery lumen 77 can terminate at a discharge port short of the bifurcation end 75 of the secondary

tubular portion 70 to permit mixing of a drug or fluid with blood perfusing through the device (see, *e.g.*, Fig. 4). Additionally, the fluid delivery lumen 77 can include one or more side perfusion ports or openings (not shown) which will enhance mixing of the drug or fluid with blood perfusing through the device. Drug delivery port 72 may have a luer adapter 34 to mate with a drug delivery source to infuse drug or fluid through the second tubular portion.

The outer surfaces or profiles of primary and secondary tubular portions 20 and 70 may optionally be constructed to seal against the inside of the vessel walls. This may be accomplished by configuring the primary and secondary tubular portions to have outside diameters or profiles that are larger than the inside diameters of the intended vessels. Referring to Fig. 2A, the primary and secondary tubular portions can be provided with inflatable low-pressure balloons 42 at each end which each have an interior which is in fluid communication with a balloon fluid delivery or inflation lumen 44 and a balloon fluid delivery port 45 which is located at the distal end of tertiary tubular portion 30. The flow of fluid from the balloon fluid delivery port 45 through the balloon fluid delivery lumen 44 will cause the balloons to inflate to engage the inner walls of the target vessels, as shown in phantom and designated with reference numeral 42'. The low-pressure balloons 42 have the advantage of allowing the bifurcated intraluminal shunt apparatus 10 to expand to effectively fit the size of the particular vessel into which the apparatus is inserted. The balloons may be at each of the three primary and secondary tubular portion ends, at two ends, or at one end. Each of the up to three balloons may optionally have a separate inflation line and delivery port (not shown).

Referring to Fig. 5, another embodiment of the invention is shown. In this embodiment, the primary and secondary tubular portions are provided with sealing cuffs or flanges 40 at each end which extend about the primary and secondary tubular portions close to proximal, distal, and bifurcation ends 26, 27, and 75, respectively. Flanges 40 are constructed of any suitable biocompatible material, preferably silicone. Flanges 40 help to secure the primary and secondary tubular portions in the vessels during use of the device 10 and to seal the vessels to force blood through the device.

A variation of the secondary tubular portion 70 is shown in Fig. 4. In this embodiment, secondary tubular portion 70 is designed to enhance the mixing of a drug or other fluid with the blood perfusing distally through the device to enhance the effectiveness

of the drug or other fluid at its target location. Tertiary tubular portion 30 is coupled to secondary tubular portion 70 and includes an inner fluid delivery lumen 77 which extends only partially along the axial length of the secondary tubular portion 70. Fluid delivery lumen 77 can also include one or more side openings or ports (not shown). A drug or other fluid can be administered via inner fluid delivery lumen 77 of tertiary tubular portion 30 and will mix with the blood perfusing distally of the bifurcation end 75 prior to exiting from the secondary tubular portion 70. This mixing of the drug or fluid with the blood may enhance the effectiveness of the drug or fluid at its target location since it may ensure that a more uniform concentration of the drug reaches its desired target, and does not bypass the target location due to a potential jetting effect. The intraluminal shunt apparatus 10'' shown is a variant of the intraluminal shunt device 10', however, this secondary lumen design can be used in any of the embodiments described herein.

A further embodiment of the intraluminal shunt apparatus of the present invention is shown in Fig. 6. The device of Fig. 6 (designated as 10''') is designed to enhance availability of blood or other fluids downstream of the distal end of the primary tubular portion. A second inner fluid delivery lumen 80 extends longitudinally from a second fluid delivery port 81 at the distal end of the tertiary tubular portion 30 to a discharge port 82 at the distal end of the primary tubular portion 20. Preferably, inner fluid delivery lumen 80 is separate and independent from inner perfusion lumen 21. The fluid delivery lumen 80 extends longitudinally along at least a portion of primary tubular portion 20, but need not extend the entire axial length of the primary tubular portion as shown. For example, the fluid delivery lumen 80 can terminate at a discharge port short of the distal end 27 of the primary tubular portion 20 to permit mixing of blood or fluid with blood perfusing through the device (not shown). Additionally, the fluid delivery lumen 80 can include one or more side perfusion ports or openings (not shown) which will enhance mixing of the blood or fluid with blood perfusing through the device. Delivery port 81 may have a luer adapter 83 to mate with a delivery source to infuse blood or fluid through the primary tubular portion.

Referring to Figs. 7A and 7B, a two-piece construction of the present invention is shown in unassembled and assembled states, respectively. This configuration facilitates the initial insertion of the shunt through the incision and into the target vessels. The primary and secondary tubular portions 20 and 70 can be inserted separately into the desired vessels, and then joined through means such as a tether 90 on the secondary tubular

portion, as shown in Fig. 7B. The proximal end 92 of the secondary tubular portion 70 may have a tapered end with a smaller diameter than that of the opening 93 on primary tubular portion 20, to facilitate the assembly of the two halves into a single piece. Tertiary tubular portion 30 is coupled to the primary tubular portion, and the secondary tubular portion is joined with the primary tubular portion such that inner fluid delivery lumens 77A and 77B are in fluid communication. Marks or notches 91 may be provided on the primary and secondary tubular portions to facilitate proper alignment of said primary and secondary tubular portions. Alternatively, the tertiary portion may be separate from the primary and secondary portions and joined to primary portion 20 in the same manner as secondary portion 70 is joined to primary portion 20 (not shown).

The sizes and cross-sectional shapes of tubular portions 20, 70, and 30 and respective separate blood perfusion, fluid delivery, and balloon inflation lumens 21, 77, and 44 may vary depending on the size of the target vessels into which they are inserted, and generally are selected to provide optimum blood perfusion and/or drug delivery through the target vessels.

The primary tubular portion 20 is of sufficient outside diameter to fit securely within the interior walls of the target vessels into which it is placed, and preferably has an outside diameter of between about 1.0 mm to about 6.0 mm, and most preferably about 1.5 mm to about 4.0 mm. The proximal portion of the primary tubular portion 23 and the distal portion of the primary tubular portion 24 need not be of the same dimensions, but may vary according to the sizes of the target vessels. The secondary tubular portion 70 is of sufficient outside diameter to fit securely within the interior wall of the target vessel into which it is placed, and preferably has an outside diameter of between about 1.0 mm to about 6.0 mm, and most preferably about 1.0 mm to about 3.0 mm.

The proximal portion of the primary tubular portion 23 and the distal portion of the primary tubular portion 24 preferably have lengths of about 0.5 cm to about 5.0 cm, and about 0.5 cm to about 5.0 cm, respectively, and most preferably about 1.5 cm, and about 1.5 cm, respectively. The secondary tubular portion 70 preferably has a length of about 0.5 cm to about 3.0 cm, and most preferably about 0.8 cm. The preferable lengths of each portion of the tubular portions will vary according to the vessels they are intended to be placed in. For example, if the secondary tubular portion is to be inserted into the

interventricular branch artery 13 for purposes of fluid delivery to the AV nodal artery 14, it should be short enough so as not to block the AV nodal artery (see, *e.g.*, Fig. 3.)

Blood perfusion lumen 21, fluid delivery lumen 77, and balloon inflation lumen 44 can have any one of a number of cross-sectional configurations as would be obvious to one of ordinary skill in the art, such as a circular, oval, crescent-shaped, or D-shaped configurations, or any other configuration including coaxial arrangements. The total combined fluid flow surface area through lumens 21 and 77 can also vary depending on the application of the device, and generally will range from between about 0.20 mm^2 and 30.0 mm^2.

Any standard cannula or catheter connected to a drug supply source (not shown) with a luer tip can be connected to the luer connection member 34 of the tertiary tubular portion 30 to administer a drug or fluid into the target vessel. If necessary, supplemental blood flow can also be delivered by connecting the luer connection member 34 to any source of arterialized blood, such as a radial artery, femoral artery, aorta, or a blood perfusion pump circuit.

For the pharmaceutical compositions described above to be most effective, those pharmaceutical compositions must be precisely delivered to the AV node of the heart upon which they act, preferably by way of the AV nodal branch artery of the heart. New surgical devices and methods are required to allow the surgeon to reliably and easily deliver such pharmaceutical compositions or other drugs or fluids to the heart or other major organ directly via the internal lumen of a coronary vessel.

The disclosed bifurcated shunt apparatus can be easily inserted directly into an incision in a coronary vessel, such as the right coronary artery or the interventricular branch artery, which delivers blood to the AV nodal branch artery. Direct access to the internal lumen of a vessel via a bifurcated intraluminal shunt has a number of advantages. First, the bifurcated intraluminal shunt can be easily employed by the cardiac surgeon under direct or endoscopic visualization without the need for x-ray fluoroscopy, which is often not present in most operating rooms. Moreover, surgeons are not very facile with drug delivery catheters delivered through a percutaneous approach, and the use of a bifurcated intraluminal shunt obviates the need for a femoral or brachial arterial puncture needed for placement of a drug delivery catheter in a vessel.

The illustrated bifurcated shunt apparatus is described in relation to placement in a branched region of a coronary vessel, such as at the junction of the right coronary artery into the interventricular branch artery and the posterior descending artery, during performance of a cardiac surgery procedure, such as a coronary artery bypass graft procedure. It should be understood, however, that the apparatus may be used in other applications. The bifurcated intraluminal shunt apparatus of the present invention may be used for the delivery of a pharmaceutical composition into the interventricular branch artery, proximal to the AV nodal artery, that is capable of causing reversible ventricular asystole in the heart while maintaining the ability of the heart to be electrically paced, as described in WO 99/07354. In this way, the pharmaceutical compositions described above, for example, which act in part on the AV node, can be effectively administered locally to the heart, in either a bolus injection or a continuous infusion to provide temporary periods of pacemaker dependent ventricular asystole, and may reduce the amount of drug required for the procedure. This allows the surgeon to perform the surgical procedure on an arrested (non-beating) heart. However, this example is given by way of illustration only and is in no way meant to be limiting.

One method of administering a drug or fluid into a patient while maintaining perfusion using the bifurcated shunt is shown in Fig. 3, and is described below with respect to a cardiac surgical procedure such as a CABG procedure. As noted above, this particular method is for illustration purposes only and is in no way intended to limit the invention to its use in the cardiac surgical procedure described below. It should be understood that the present invention can be readily placed in any branched vessels, especially those that supply blood to or drain blood from any major organ and can be used for any diagnostic or therapeutic medical or surgical procedure such as a neurosurgery or other vascular surgery procedure. The present invention can be used to deliver any pharmaceutical or diagnostic agent, blood, or other fluid into any target vessel depending on the requirements of the particular medical or surgical procedure. Further, the invention can be used for closed-chest or open-chest surgical procedures.

A CABG procedure, like any other cardiac surgical operation, requires adequate access to the heart prior to placement of the shunt apparatus 10'. Different methods of access can be used by the surgeon to expose the heart such as an anterior left/right thoracotomy, a partial or median sternotomy, a parasternal thoracotomy, and an upper

midline incision. In the described methods the heart is exposed by a partial or median sternotomy. With the heart so exposed, an incision 15 is made in the right coronary artery 11 or other target vessel at the desired drug delivery site, preferably near the junction to the posterior descending artery 12 and the interventricular branch artery 13. After preparing the incision or opening, a bifurcated intraluminal shunt device having a bifurcated perfusion lumen and at least one inner fluid delivery lumen is inserted through the incision. In a preferred embodiment, a shunt apparatus such as the one shown in Fig. 2A is provided and the proximal end 26, the distal end 27, and the bifurcation end 75 are introduced into the right coronary artery 11 through the incision. The proximal end 26 of the primary tubular portion 20 is positioned upstream of the incision site in the right coronary artery and the distal end 27 of the primary tubular portion 20 is positioned downstream of the incision site in the posterior descending artery 12. The bifurcation end 75 of the secondary tubular portion 70 is positioned downstream of the incision site in the interventricular branch artery 13. Balloons 42 are inflated by fluid flowing into the balloon fluid delivery port 45, firmly positioning the primary and secondary tubular portions 20 and 70 within the internal walls of the right coronary artery 11, posterior descending artery 12, and interventricular branch artery 13. Alternatively, the flanges 40 may be used to firmly position the primary and secondary tubular portions 20 and 70 within the internal walls of the right coronary artery 11, posterior descending artery 12, and interventricular branch artery 13, to seal the vessel to maximize blood perfusion through it.

A drug or fluid is then delivered through a cannula or catheter having a luer connector (not shown) connected to luer connector 34 of tertiary tubular portion 30. Preferably, the drug comprises a pharmaceutical composition which is capable of inducing precise and controlled periods of reversible ventricular asystole of the heart while maintaining the ability of the heart to be electrically paced. Preferably, the pharmaceutical composition comprises a combination of an atrioventricular ("AV") node blocker and a β–blocker. As used herein, the term "AV node blocker" refers to a compound capable of reversibly suppressing autonomous electrical conduction at the AV node, while still allowing the heart to be electrically paced to maintain cardiac output. Preferably, the AV node blocker, or the composition comprising the AV node blocker, reduces or blocks ventricular escape beats and cardiac impulse transmission at the AV node of the heart, while the effect on depolarization of the pacemaker cells of the heart is minimal or

nonexistent. The β–blocker is preferably provided in an amount sufficient to substantially reduce the amount of AV node blocker required to induce ventricular asystole. For example, the AV node blocker may be present in the composition in an amount which is 50% or less by weight, or optionally about 1 to about 20% by weight of the amount of AV node blocker alone required to induce ventricular asystole.

The pharmaceutical composition, such as an AV node blocker, capable of causing ventricular asystole in a preferred embodiment is a cholingeric agent such as carbachol, although other cholingeric agents may be used as well. In the preferred embodiment, the β–blocker is propranolol, although other suitable β–blockers may be used as well. The administration of the β–blocker is preferably prior to, or contemporaneously with, the administration of the cholinergic agent, and results in a synergistic effect between the β–blocker and the cholinergic agent. The use of a cholinergic agent, such as carbachol, in combination with a β-blocker, such as propranolol, produces ventricular asystole at significantly reduced dosages of the cholinergic agent, while maintaining a short half-life and rapid onset of effect.

The cholinergic agent, such as carbachol, is generally administered in an initial intracoronary bolus of about 5 to 150 μg/kg body weight of patient, or about 2 to 20 μg/kg body weight of patient, for example, about 4 to 16 μg/kg, or about 6 to 14 μg/kg, or in one embodiment, about 8 to 12 μg/kg body weight, in a suitable pharmaceutically acceptable carrier or diluent. The bolus infusion of the cholinergic agent is preferably followed by a continuous infusion of the cholinergic agent. The infusion rate is generally about 0.1-4.8 μg/kg body weight patient/min, preferably about 0.1-1.2 μg/kg/min, or about 0.1-1.0 μg/kg/min. A typical total adult dosage of the cholinergic agent, such as carbachol, is about 0.1 mg to 15 mg for a 120 min period of ventricular asystole. The dosage may be adjusted depending on the surgical procedure. The β–blocker, such as propranolol, is typically administered in a single bolus in a dosage amount of about 0.01 to 0.07 mg/kg body weight of patient, for example 0.01 to 0.05 mg/kg, or about 0.01 to 0.04 mg/kg. The total amount of propranolol administered is typically about 0.1 mg to 5 mg, for example about 2 to 4 mg, or about 3 mg.

As described above, the combination of AV node blocking using an effective dosage amount of an AV node blocker (such as carbachol), and/or other means of

stimulating the AV node such as vagal nerve stimulation, in combination with an effective dosage amount of a β–blocker (such as propranolol) produces precise and controlled prolonged periods of reversible ventricular asystole of the heart while maintaining the ability of the heart to be electrically paced.

If necessary, continuous drug infusion can be interrupted and supplemental blood flow can be provided in the anterograde direction by connecting the luer connector member 34 to an appropriate source of oxygenated blood such as a radial artery, femoral artery, aorta, or blood pump perfusion circuit, or any other suitable blood supply.

Electrical pacing wires are connected to the right ventricle and/or left ventricle and are used to pace the heart to maintain the patient's blood circulation during the periods in which the surgeon is temporarily not performing the surgical procedure. Thus, for example, in a coronary artery bypass graft procedure (such as a left interior thoracic artery (LITA) to left anterior descending artery (LAD) anastomosis), the surgeon can control the pacing of the heart with a convenient foot pedal and can controllably stop the heart as sutures are placed in the vessel walls. When the coronary artery bypass graft procedure is complete, the intraluminal shunt apparatus 10' can be removed by applying gentle pressure on the tertiary tubular portion 30 and then removing the primary and secondary tubular portions 20 and 70 from the incision. If the graft is being placed at the site of the shunt incision (thus minimizing the number of incisions made into the coronary vessel), the device 10' can be removed, the graft placed into position (*e.g.*, by parachuting technique) and then secured to the coronary artery by stitching or other known fastening means.

While the above is a detailed description of particular embodiments of the present invention, various alternatives, modifications and equivalents may be used. It be understood that any combination of the above bifurcated intraluminal shunt components or constructions, including but not limited to, balloons, flanges, bevelled edges, configurations facilitating drug and blood mixing, and second independent inner fluid delivery lumens, are within the scope of the present invention. Therefore, the above description should not be taken as limiting the scope of the invention, which is defined by the following claims and their equivalents.

CLAIMS

1. A bifurcated intraluminal shunt for the administration of a drug or fluid into one vessel which branches from another vessel while maintaining blood perfusion through both of said vessels, comprising:

a primary and a secondary tubular portion each adapted for insertion into said vessels. said primary tubular portion having a proximal end and a distal end, and the secondary tubular portion having a distal end spaced from said primary tubular portion; said portions forming at least one bifurcated perfusion lumen; and

at least one fluid delivery lumen extending longitudinally along at least a portion of the secondary tubular portion, having at least one discharge opening and being separated from said perfusion lumen.

2. A drug delivery apparatus comprising a primary tubular portion having a proximal end and a distal end, a secondary tubular portion extending from said primary tubular portion between said proximal and distal ends and having a distal end, said primary and secondary tubular portions adapted to be inserted into branched vessels of a human patient.

3. The drug delivery apparatus of claim 2, wherein said primary and secondary tubular portions are adapted to be inserted into the right coronary artery, the posterior descending artery, and the interventricular branch artery.

4. A kit for conducting a surgical procedure is provided comprising:

a pharmaceutical composition capable of inducing reversible ventricular asystole in the heart of a patient while maintaining the ability of the heart to be electrically paced; and

a bifurcated intraluminal shunt having a bifurcated perfusion lumen and a drug delivery lumen separated from said perfusion lumen.

5. A method for delivering a pharmaceutical composition into a branch of a coronary artery comprising:

placing a bifurcated intraluminal shunt having first , second and third legs is placed in a human patient with one leg extending into the interventricular branch of the patient; and

delivering through the leg extending into the interventricular branch a pharmaceutical composition capable of inducing reversible ventricular asystole in the heart of the patient while maintaining the ability of the heart to be electrically paced.

6. The method of claim 5 further including forming an opening in the coronary artery and delivering the shunt through the opening such that the drug delivery leg extends into the interventricular branch.

7. The method of claim 6 further including removing the shunt and securing a graft vessel to the coronary artery around said opening.

8. The method of claim 6, wherein the bifurcated intraluminal shunt is placed at the site of an anastomosis.

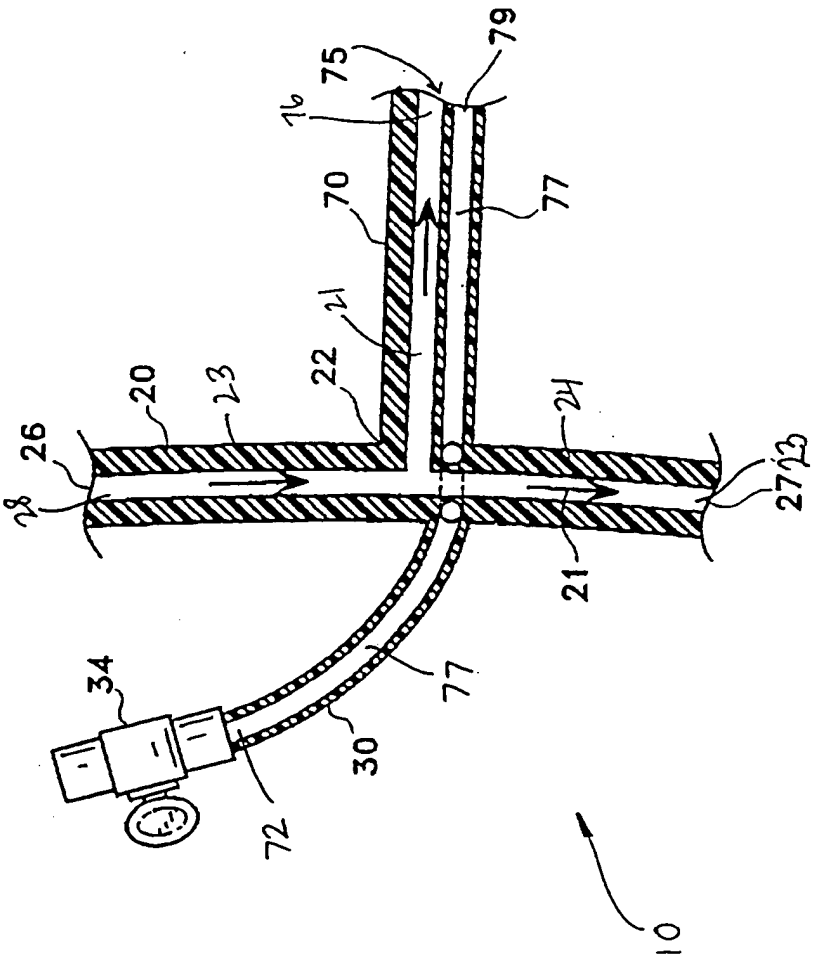


FIG. 1

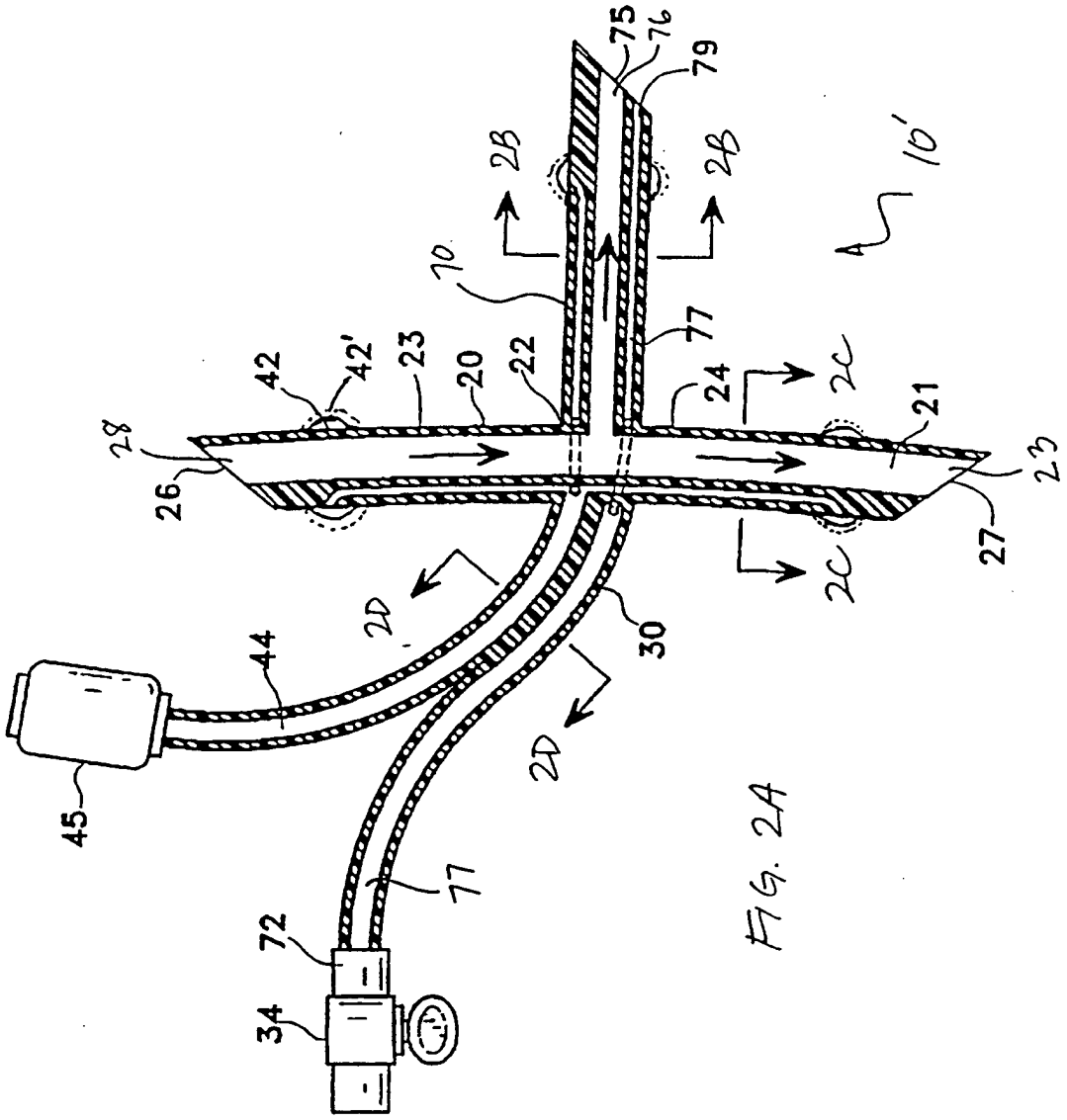


FIG. 2A

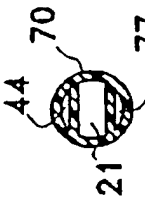


FIG. 2B

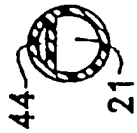
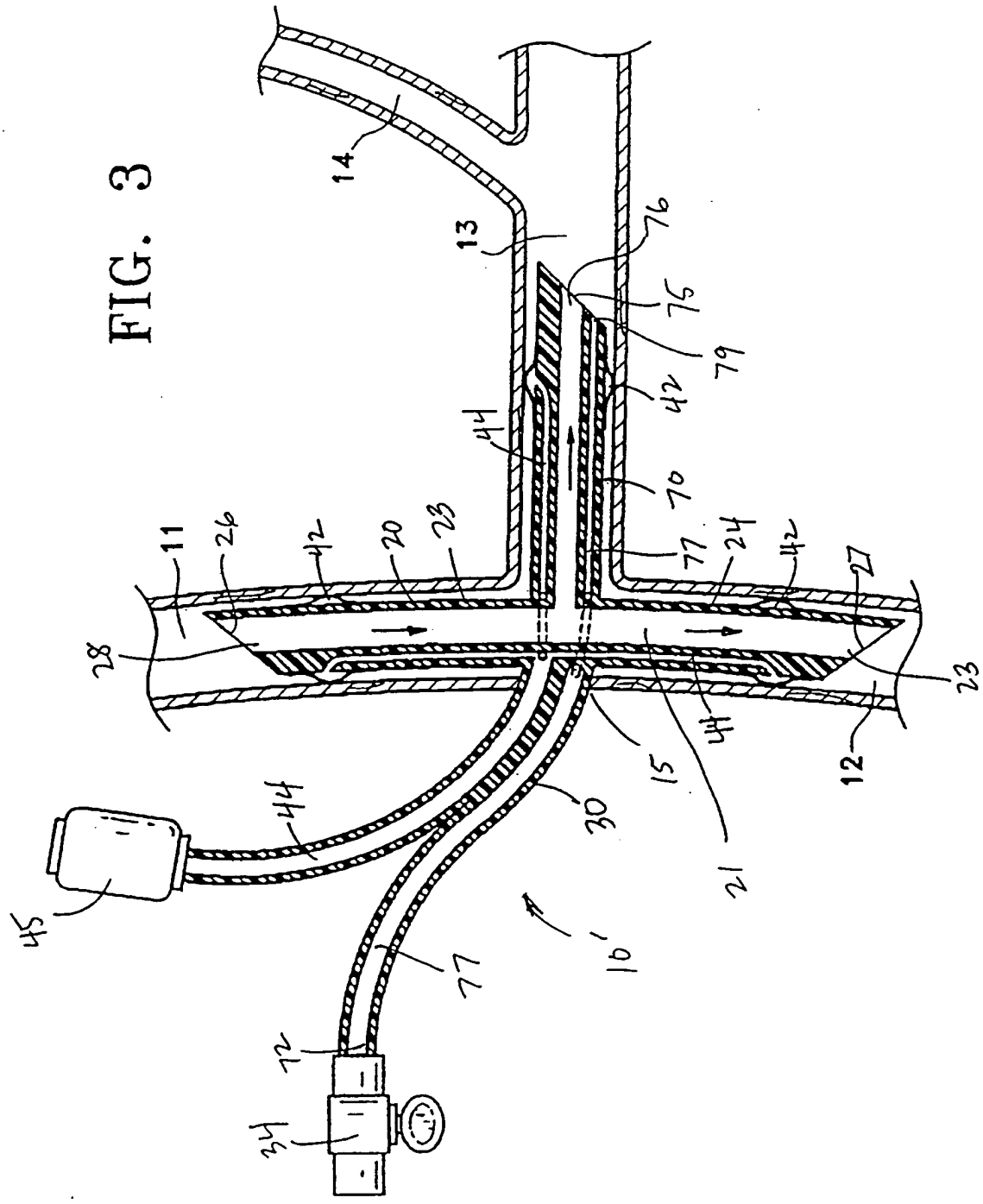


FIG 2C

FIG 2D

FIG. 3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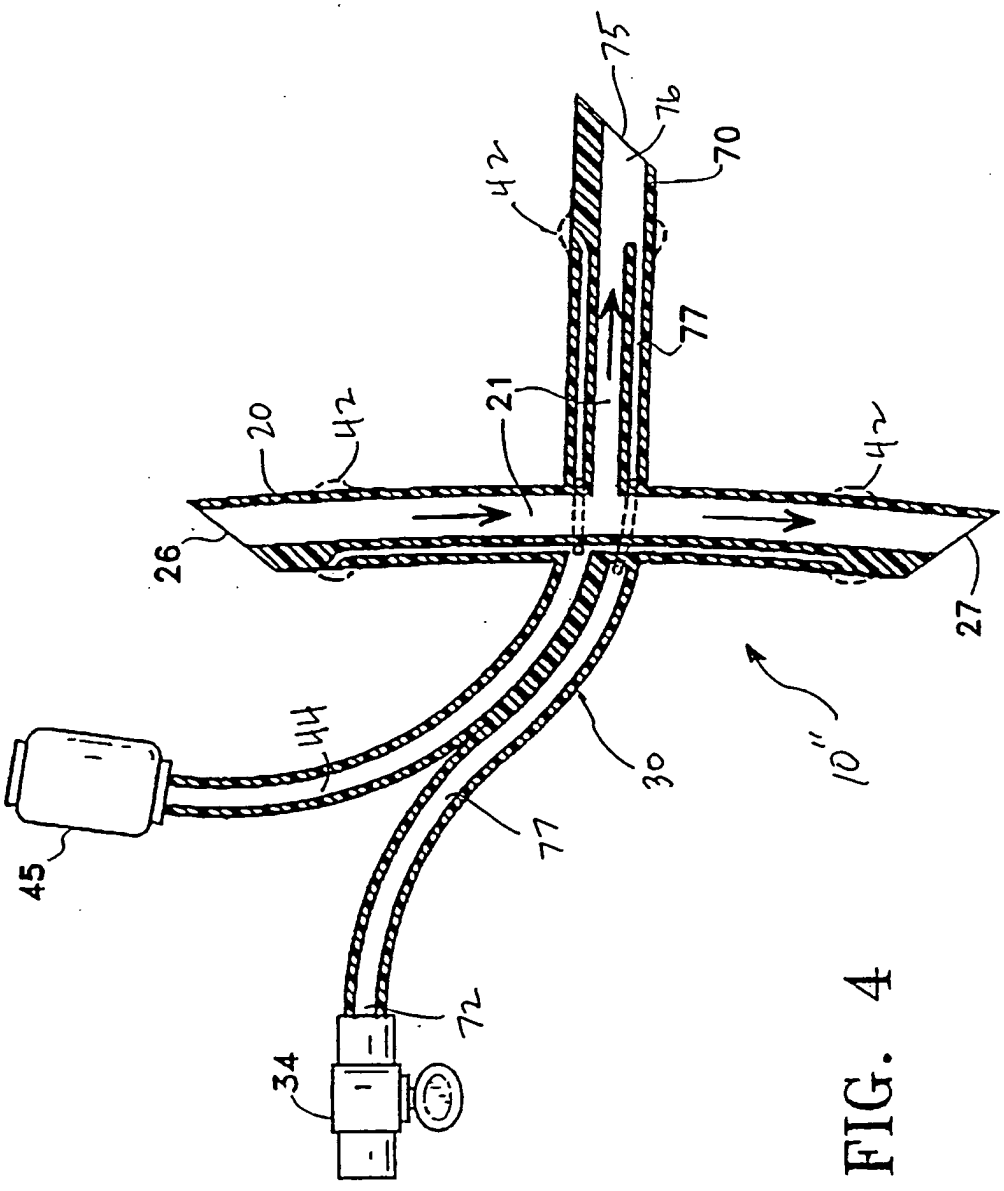

FIG. 4

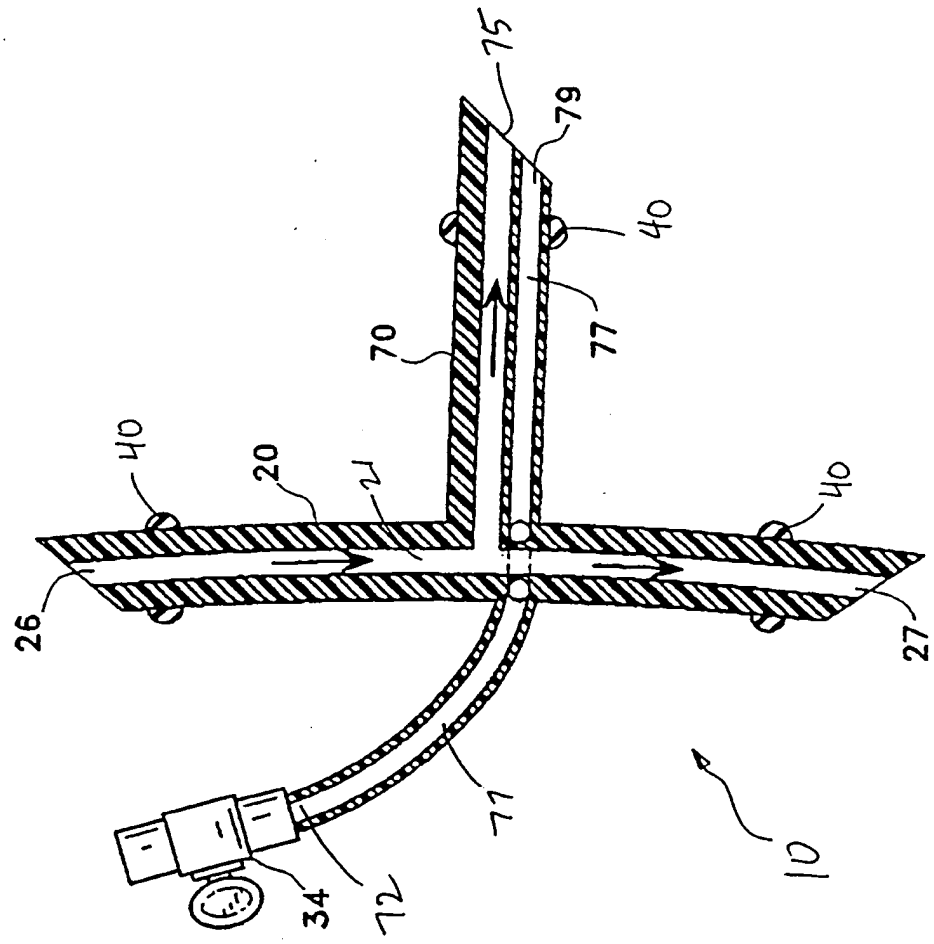

FIG. 5

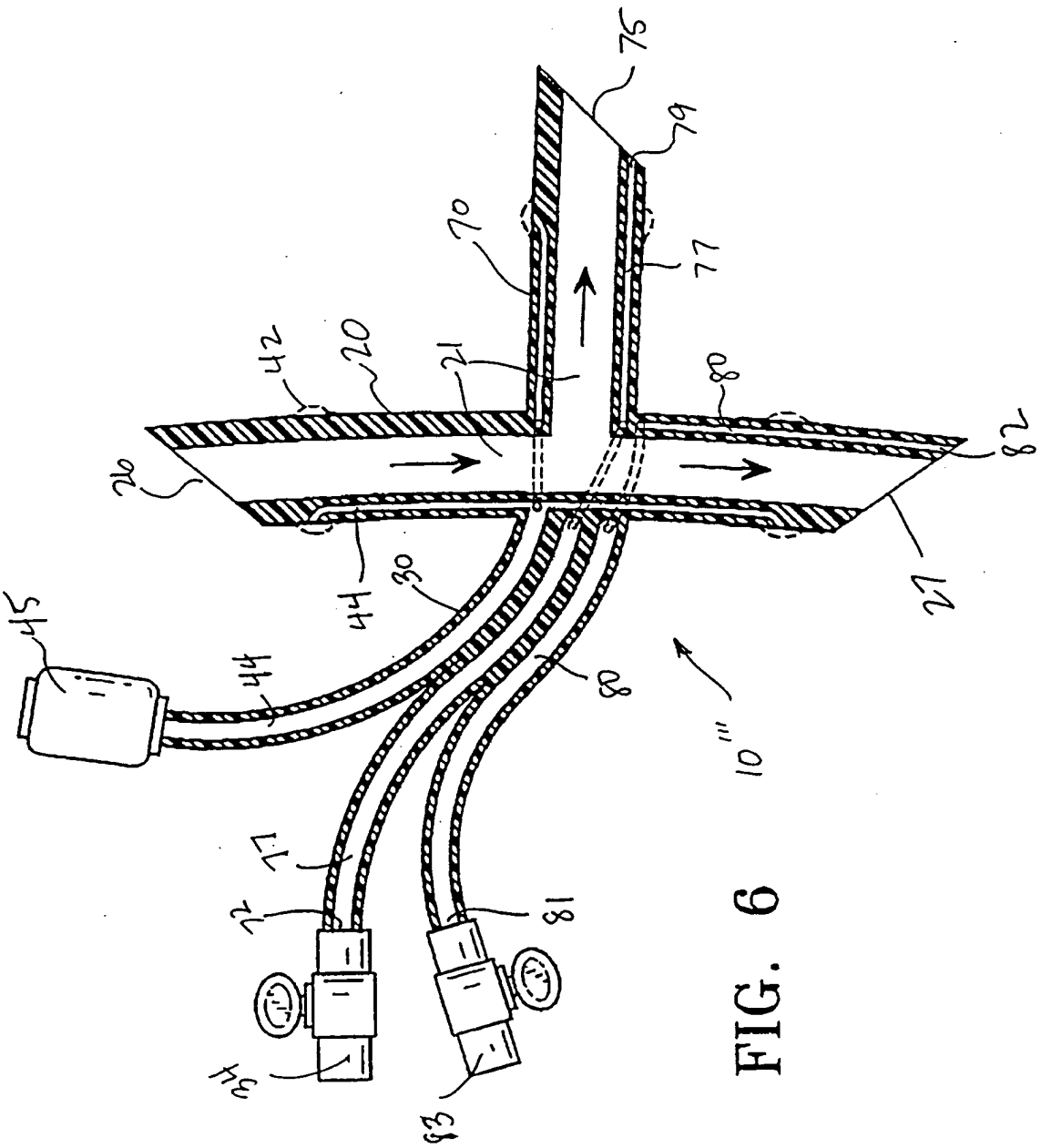

FIG. 6

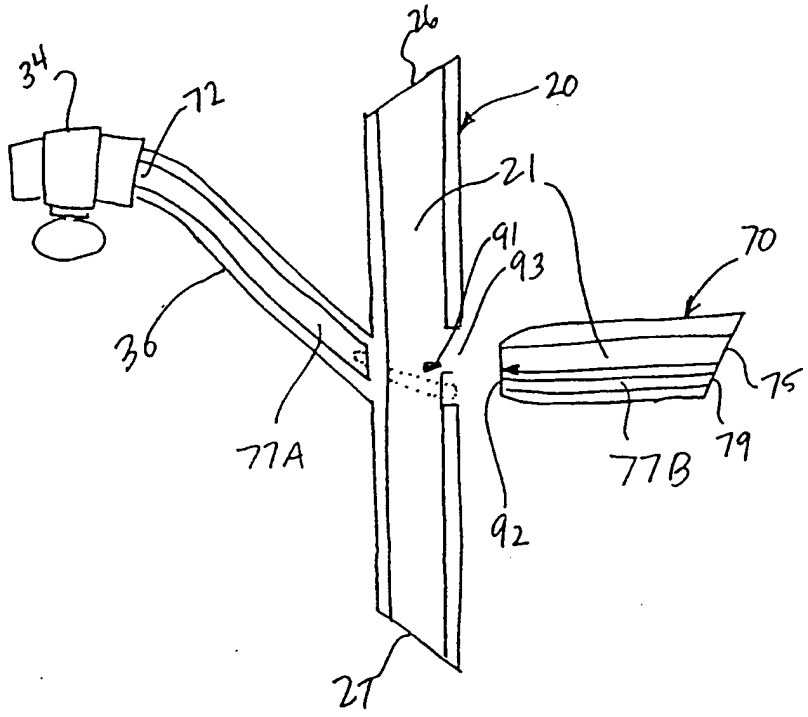
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FIG. 7A

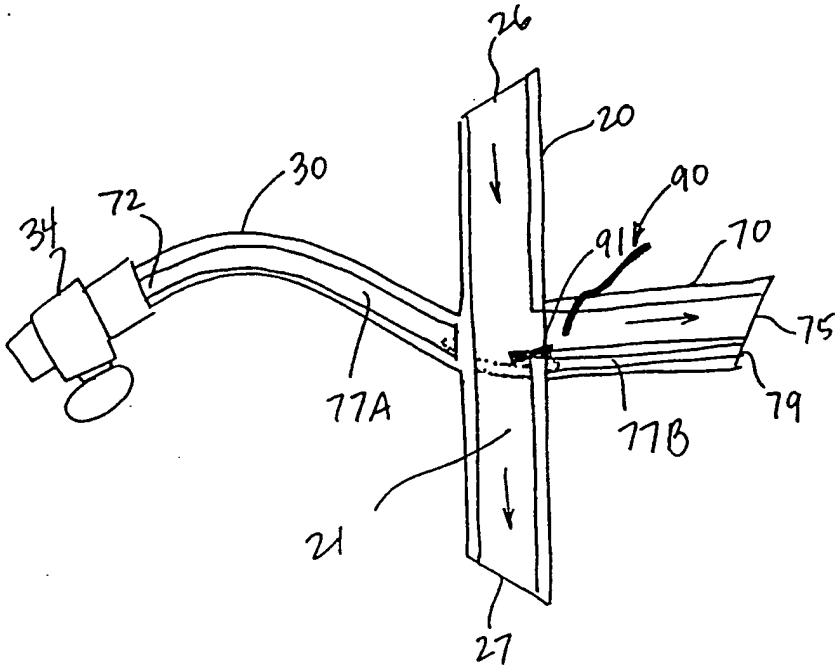
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FIG. 7B